

Chemical Enrichment of Intracluster and Intergalactic Medium
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Galactic Winds in Starburst Irregular Galaxies

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Abstract.

In this paper we present some results of numerical simulations concerning the development of galactic winds in starburst galaxies. In particular, we focus on a galaxy similar to IZw18, the most metal-poor galaxy locally known. We compute the chemo-dynamical evolution of this galaxy, considering the energetic input and the chemical yields originating from Supernovae (SNe) of Type II and Ia and from intermediate-mass stars. We consider both single, instantaneous starburst and two starburst separated by a quiescent period. In all considered cases a metal enriched wind develops and in particular the metals produced by Type Ia SNe are ejected more efficiently than the other metals. We suggest that two bursts of star formation, the first being weaker and the last having an age of some tenth of Myr, can satisfactorily reproduce the abundances and abundance ratios found in literature for IZw18.

1. Introduction

Many Dwarf Irregular Galaxies (DIG) are known to be in a starburst phase, or are believed to have experienced periods of intense star formation in the recent past. These galaxies are generally called Blue Compact Dwarfs (BCD). Energetic events associated with star formation (stellar winds and Supernova explosions) may sweep the interstellar gas out of the region actively forming stars, thus creating galactic winds. Observational evidences of outflows have been found recently in many edge-on starburst galaxies, like NGC1705, NGC1569 and NGC3628. Martin (1998) found that large expanding supershells are common byproducts of massive star formation in dwarf galaxies.

Both dynamical and chemical simulations of these galaxies have suggested the existence of a ‘differential galactic wind’, in the sense that, after a starburst event, these objects would loose mostly metals (Pilyugin 1992, 1993; Marconi, Matteucci & Tosi 1994; MacLow & Ferrara 1999; D’Ercole & Brighenti 1999). However in none of these studies, detailed chemical and dynamical evolution was taken into account at the same time.

Among BCD, the galaxy IZw18 (the most metal-poor galaxy locally known) constitutes the best candidate for a truly “young” galaxy. However, there is still a debate in literature on whether IZw18 is experiencing the first burst of star formation or not. Evolutionary population synthesis models by Mas-Hesse & Kunth (1999) show that the present burst is very young (between 3 and 13 Myr) and the contribution of older stars, if any, is negligible. Dynamical arguments (Martin 1996) suggest a single burst with an age between 15 and 27 Myr. Recent Color Magnitude Diagram (CMD) studies of IZw18, both in the optical (Aloisi, Tosi & Greggio 1999; hereafter ATG) and in the infrared (Östlin 2000), revealed the presence of an underlying older population, with an age of some 10^8 yr. Legrand (2000) and Legrand et al. (2000) proposed instead a low and continuous star formation regime for IZw18.

We study, through numerical simulations, the dynamical and chemical evolution of a gas-rich dwarf galaxy whose structural parameters resembles IZw18. We consider single instantaneous starburst or a couple of starburst separated by a quiescent period. We include effects (both energetical and chemical) of Type II and Type Ia SNe in a detailed way. The aim of this work is to test the ‘differential wind’ hypothesis with an hydrodynamical approach and to find constraints for the number and for the age of the starbursts in IZw18.

2. The model

We consider a gaseous component in hydrostatic isothermal equilibrium with the centrifugal force and a potential well. The potential well is the sum of a quasi-isothermal dark halo ($M_{dark} \simeq 6.5 \cdot 10^8 M_\odot$) and an oblate King profile. The mass of gas inside the galactic region (an ellipsoid with dimensions 1 Kpc \times 730 pc) is $\sim 1.7 \cdot 10^7 M_\odot$.

To describe the evolution of the ISM, we adopt a 2-D hydrocode, with source terms describing the rate of mass and energy return from the starbursts, taking into account SNe of Type II and Ia and low and intermediate-mass stars (IMS). By using passively evolving tracers, we are able to follow the evolution, in space and time, of some chemical elements of particular astrophysical interest. The production of these elements are obtained following the nucleosynthesis prescriptions from various authors: Woosley & Weaver (1995) for SNeII, Nomoto, Thielemann & Yokoi for SNeIa and Renzini & Voli (1981), case R, or van den Hoek & Groenewegen (1997), case V, for IMS. See Recchi, Matteucci & D’Ercole (2001) for more details about model prescriptions.

In the single-burst model, the mass of stars formed is $M_\star = 6 \cdot 10^5 M_\odot$, whereas in the two-burst model we consider a weaker first burst (the mass of stars is $10^5 M_\odot$). After 300 Myr (model M300) or 500 Myr (model M500) we consider that 10% of cold gas inside a central region (a sphere of 200 pc of radius) is turned into stars. The initial abundances of this second stellar generation are simply the metallicity of the cold gas in the central region at the onset of the burst. According to the results of ATG, we consider also a flatter IMF (model M300F), with a slope $x = 0.5$. More details about these two-burst models are in Recchi et al. (2001b).

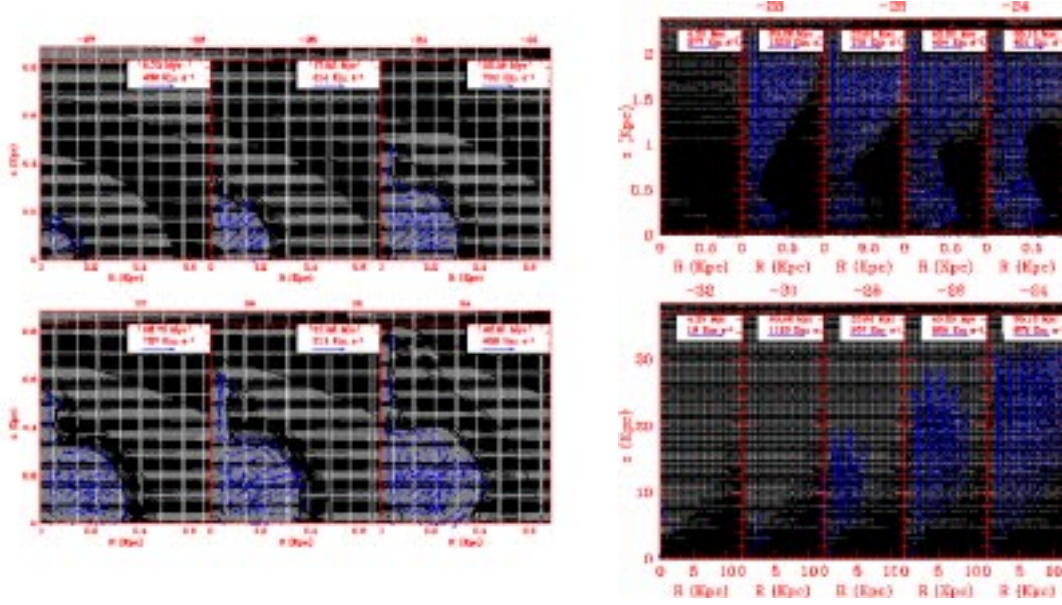


Figure 1. Density contours and velocity field for the single-burst model (left panels) and two-burst model M300 (right panels) at different epochs (age of the burst is labelled inside each panel). The density scale (logarithmic) is labelled in the strip on top of the figures. For what concerns model M300 (right panels), upper panels are a zoom in the central regions of what shown in the lower panels.

The efficiency of SN heating is assumed to be very low for Type II SNe. In particular, following results of Bradamante, Matteucci & D’Ercole (1998), we consider a thermalization efficiency of $\eta_{II} = 0.03$ for the single-burst model and $\eta_{II} = 0.05$ for the two-burst model, namely only 3% (or 5%) of the explosion energy is able to thermalize the ISM, while the rest is radiated away. Type Ia SNe instead explode in an already heated and diluted medium, thus their thermalization efficiency is assumed to be $\eta_{Ia} = 1$. There is debate in literature about the correct value of thermalization efficiency. In particular, Strickland & Stevens (1999) assume a value $\eta = 1$ (see also the contribution of Strickland in this volume). The reason of our choice is that the number of SNeII exploding in our model is rather low, thus the time interval between single explosions ($\sim 6 \cdot 10^4$ yr) is larger than the typical cooling time-scale, thus remnant of Type II SNe evolve as single SNR. In addition, we tried to run simulations with an efficiency $\eta = 1$ also for Type II SNe and the galaxy is quickly devoided of gas, thus the actual gas content in IZw18 rules out the possibility of an high η_{II} .

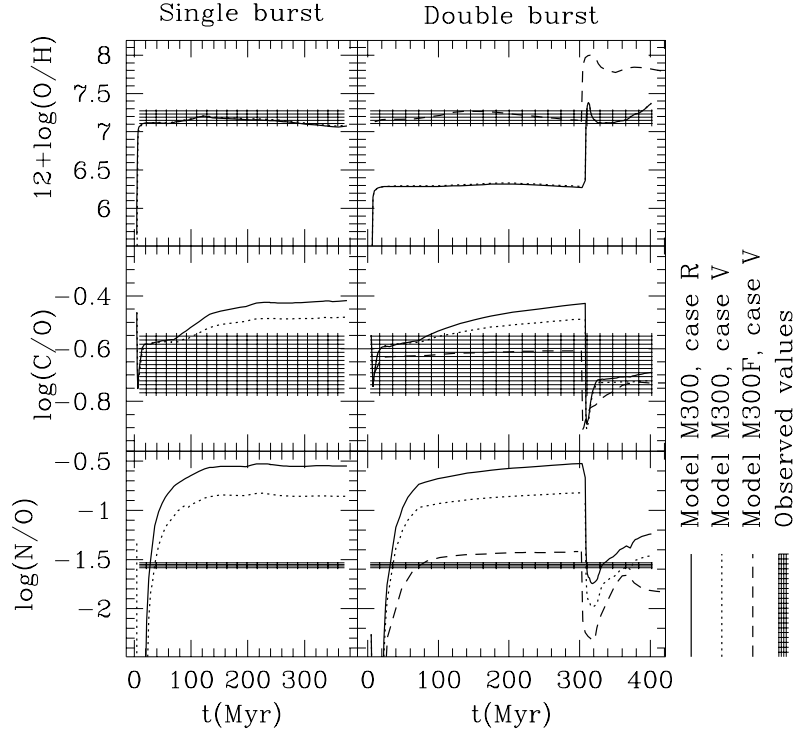


Figure 2. Evolution of O, C/O and N/O for the single-burst model and the models M300 and M300F. Left panels represent the evolution of the single-burst model with RV81 yields (solid line) and VG97 (dotted line). In the right panels the evolution of model M300 with RV81 yields (solid line) and VG yields (dotted lines), together with model M300F, VG97 yields (dashed lines) are shown

3. Results

3.1. Dynamical results

Single-burst model Owing to the energy released by Type II SNe, a galactic wind develops. It expands faster along the z direction, where the ISM density gradient is steeper. SNeII activity lasts for only 29 Myr (the lifetime of a $8 M_{\odot}$ star), then is replaced by a weaker SNIa wind, not strong enough to sustain the galactic outflow (Fig. 1). After ~ 300 Myr, the expanding ISM is diluted enough and the hot bubble finally breaks out through a funnel. Most of the SNeII ejecta remains locked into the cold and dense shell, whereas metals ejected by SNIa are easily channelled along the funnel. Iron, mostly produced by Type Ia SNe, is thus easily lost by the galaxy and the $[\alpha/\text{Fe}]$ ratios outside the galaxy are lower than inside (see section 4). Owing to the low evolution of the superbubble, the internal cavity becomes soon radiative (i.e. radiates an energy comparable to the thermal energy content of the shocked wind) thus after ~ 10 Myr most of metals are in a cold phase.

Two-burst model Owing to the low luminosity of the first burst, after ~ 300 Myr a galactic wind still does not develop. For the model M300 a cold, dense shell of dimensions 200×100 pc forms and outside this region the ISM is almost unperturbed. The impact of the second generation of stars on the ISM dynamics is rather vigorous. Already after ~ 30 Myr after the onset of the second burst a breakout occurs (see Fig. 1) and the gas produced during this second burst is easily lost along the galactic chimney.

The hypothesis of a differential wind is substantially confirmed in these simulations: metals are ejected more easily than pristine ISM. Also for the two-burst model the ejecta of Type Ia SNe are lost more easily, but this effect is less evident compared to single-burst model. The consequence of this selective losses of metals is that $[\alpha/\text{Fe}]$ ratios outside the galaxy are lower than inside.

3.2. Chemical results

The evolution of Oxygen abundance and C/O and N/O ratios for the single-burst model, cases R and V (left panels) and for the two-burst models M300, cases R and V and M300F, case V only (right panels) are shown in Fig. 2. Shaded areas represents the observed values found in literature for IZw18

Single-burst model reproduces the observed abundances of IZw18 only for a very short time, at an age of ~ 31 Myr. After this time, N/O ratio begins to increase over the permitted range, owing to the N produced by intermediate-mass stars. Model M300 is able to reproduce observed abundances of IZw18 for a wider range of times: between 25 and 40 Myr after the onset of the second burst (case R) and between 50 and 70 Myr (case V). The M300F model produces too much oxygen during the first burst of star formation and does not fit the observed abundance ratios, unless the age of the second burst is extremely short (around 4 Myr). Model M500 (not shown here) is able to fit abundances found in literature for an evolutionary time between 40 and 80 Myr.

4. Conclusions

Our main conclusions can be summarized as follows:

- energetic events associated with the starbursts, are able to trigger a galactic wind and the metals produced in the burst leave the galaxy more easily than the unprocessed gas.
- In particular, the ejecta of Type Ia SNe are lost more efficiently than Type II SNe, because this kind of explosions occur in a hot and rarefied medium. the consequence is that $[\alpha/\text{Fe}]$ ratios outside the galaxy are lower than inside. This effect is more evident in the single-burst model.
- Single-burst model reproduces the observed abundances in IZw18 after ~ 31 Myr, while for the two-burst model we obtain agreement with the data found in literature for wider ranges of time, when the second starburst has an age of some tenth of Myr, depending on the adopted model and nucleosynthesis prescriptions.

- The classical Salpeter IMF should be preferred over a flatter one which would predict a too high oxygen abundance.
- Finally, we can suggest that a first, weak burst of star formation, occurred more than 300 Myr ago, followed by a stronger one, having an age of some tenth of Myr, with a Salpeter IMF, best reproduces the properties of IZw18.

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